MILLIMETER WAVE SURFACE MOUNT FILTER

Field of the Invention

This invention relates to the field of millimeter wave filters, and more particularly, this invention relates to millimeter wave filters, such as parallel coupled line filters formed as hairpin filters.

Background of the Invention

Almost every high frequency, RF module manufactured today requires a number of filters, including millimeter wave filters. For example, a transceiver will typically have an image reject filter and one local oscillator (LO) reject filter. The estimated number of RF modules built worldwide, including cell phones, is now over 600 million.

Traditionally, high performance filters at frequencies greater than 800 MHz for use in millimeter wavelength applications are designed and fabricated using dielectric resonators. Tight design and manufacturing tolerances are required to achieve a desired filter response at these high frequencies. The filter length and width usually varies as a function of frequency band, substrate parameters, and performance requirements. These filters are expensive, typically $10 each at the present time, and are usually hand-tuned during fabrication. Conventionally designed

parallel, coupled line filters are not practical at and below L-band frequencies because of their large size. A standard three pole, 1.5 GHz hairpin filter is about 800 mils by about 400 mils and printed on an alumina (Er=9.9) substrate.

Commonly assigned U.S. Patent No. 6,483,404, issued November 19, 2002, the disclosure which is hereby incorporated by reference in its entirety, discloses a high performance, millimeter wave radio frequency filter using standard thick film technology and manufacturing tolerances. The invention disclosed in this '404 patent is an improvement over prior art parallel-coupled line filters where the length of the filter is proportional to the number of poles and RF wavelength, for example, as commonly manufactured using thin film, filter designs.

In the incorporated by reference '404 patent, a high performance, millimeter wave filter uses low temperature, co-fired ceramic thick film technology and is operative as a high "Q" filter. This filter is small and can include vertically stacked resonators positioned in a multilayer, low temperate co-fired ceramic film allowing even smaller designs. The disclosed resonators can form parallel, coupled line filters, including a hairpin filter formed by a number of hairpin resonators cascaded together. In one aspect of the '404 patent, microstrip and stripline interface connections are used to stack the filters in the low temperature co-fired ceramic layers, allowing the filter to be used for standard surface mount packages. The filters are desensitized to traditional critical tolerances associated with thin film technology and compensate for bandwidth and return loss degradation caused by wider tolerances associated with thick film technology. These type of filters disclosed in the

incorporated by reference '404 patent can be manufactured for high performance capabilities at a fraction of the cost of thin film filters. Additionally, these types of filters, including hairpin filters, can eliminate filter size variation versus frequency and reduce the size of the filter by 50%.

In another aspect of the disclosed '404 patent, the millimeter wave filter includes a dielectric base plate having opposing surfaces. A ground plane layer is formed on a surface of the dielectric base plate. At least one low temperature, co-fired ceramic layer is positioned over the ground plane layer and defines an outer filter surface. A plurality of coupled line millimeter wavelength resonators, such as parallel coupled resonators, including hairpin resonators, are formed as stripline or microstrip and positioned on the outer filter surface.

Radio frequency terminal contacts are positioned on the surface of the dielectric base plate opposite the at least one low temperature co-fired ceramic layer. Conductive vias extend through the at least one low temperature co-fired ceramic layer, ground plane and dielectric base plate and each interconnect radio frequency terminal contacts and the at least one coupled line resonator.

Hairpin filters are advantageously used and have been typically about half the size of traditional parallel-coupled line filters. A hairpin filter allows size reduction from a parallel-coupled line structure. A filter of this type usually is a cascade of U-shaped resonators. A standard tapped hairpin filter could occupy about 850 mils by 450 mils, including sufficient area beyond the hairpin loops to maintain consistent dielectric properties. Printed hairpin filters can

sometimes be excessively large at L-band frequencies and are often replaced with lumped component filters.

Summary of the Invention

It is therefore an object of the present invention to provide a millimeter wave, thick film surface mount filter as a hairpin filter with reduced size.

The present invention is a very small, low cost, high performance RF filter using standard thick film technology and manufacturing tolerances. It incorporates a unique, hairpin resonator folded upon itself and manufactured on ceramic material. No other packaging is required. It achieves high radio frequency performance using standard thick film technology while forming a high Q filter in a very small space using folded hairpin resonators. The filter can be designed for a standard surface mount assembly and can achieve high performance filtering that is desensitized to traditional critical tolerance associated with dielectric resonator technology. Thus, in accordance with the present invention, high precision filters can be achieved at a fraction of the cost of dielectric resonator filters and superior performance achieved that is greater than performances achieved with typical SAW filters, including lower insertion losses and lower group delay.

A millimeter wave filter for surface mount applications, in accordance with the present invention, includes at least one low temperature, co-fired ceramic layer defining an outer filter surface. A plurality of parallel, coupled line millimeter wavelength hairpin resonators are each formed from a single stripline or microstrip on the outer filter surface. Each hairpin

resonator is folded back upon itself into substantially parallel resonator lines.

In one aspect of the present invention, each hairpin resonator is folded back upon itself into at least six, substantially parallel resonator lines. The at least one low temperature, co-fired ceramic layer can comprise alumina that is about 5 to about 25 mils thick. A ground layer can be formed opposite the outer filter surface. A ground layer can include one of a layer of gold or silver. It can include input and output terminals on a surface opposite the outer filter surface.

A conductive via could extend through the at least one low temperature, co-fired ceramic layer and interconnect respective input and output terminals and a hairpin resonator. The hairpin resonators that are folded back upon themselves could form a millimeter wave filter that is about 320 mil by about 320 mil.

In yet another aspect of the present invention, a plurality of low temperature, co-fired ceramic layers and interposed ground plane layers form a multilayer, low temperature, co-fired ceramic substrate board. A plurality of millimeter wavelength hairpin resonators are formed on the ceramic layers and each folded back upon themselves into parallel resonator lines. A dielectric cover is positioned over the outer filter surface and can include a metallized interior surface spaced from the resonators for generating a predetermined cut-off frequency.

Brief Description of the Drawings

Other objects, features and advantages of the present invention will become apparent from the detailed description of the invention, which follows

when considered in light of the accompanying drawings in which:

FIG. 1 is a fragmentary, plan view of a low temperature, co-fired ceramic (LTCC) filter disclosed in the incorporated by reference '404 patent that could be modified for use with the present invention.

FIG. 2 is a fragmentary, sectional view of the filter shown in FIG. 1, and formed with an alumina carrier plate, a layer of low temperature co-fired ceramic tape, and a ground layer.

FIG. 3 is a fragmentary, bottom plan view of the filter shown in FIG. 1.

FIG. 4 is a fragmentary, plan view of a multilayer six-pole filter that is created by cascading three, two-pole filters in different LTCC layers, which could be modified for use with the present invention.

FIG. 5 is a fragmentary, sectional view of the filter of FIG. 4 and showing stacked low temperature co-fired ceramic layers.

FIG. 6 is a fragmentary, bottom plan view of the filter shown in FIG. 4.

FIG. 7 is a plan view of the filters of the present invention that could be formed by modifying structures shown in FIGS. 1-6, and showing hairpin resonators folded upon themselves.

FIGS. 8A and 8B are plan views looking from the top and bottom of a surface mount package configuration of the present invention.

Detailed Description of the Preferred Embodiments

The present invention will now be described more fully hereinafter with reference to the accompanying drawings, in which preferred embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should

not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. Like numbers refer to like elements throughout.

The present invention advantageously provides a small, low cost, high performance, millimeter wave RF filter using standard thick film technology and manufacturing tolerances. The high performance filter of the present invention is designed with unique hairpin resonators that are folded upon themselves and manufactured on ceramic material, such as LTCC. No other packaging is required. It achieves high RF performance using standard thick film technology, while achieving a high Q in a small space. The filter of the present invention can be designed for standard surface mount assembly and desensitized to traditional critical tolerances associated with dielectric resonator technology. The present invention provides a high performance filter at a fraction of the cost of a dielectric resonator filter and achieves superior performance as compared to SAW filters, including lower insertion losses and lower group delay.

The present invention has the arms of each of the hairpin resonators of a hairpin filter folded upon themselves to reduce the overall size significantly. The length of the hairpin resonators in a hairpin filter in one aspect of the present invention is a quarter wavelength long at the design frequency. A fractional bandwidth of the narrow band filter is less than 1.5% and it takes more time to synthesize than on regular filters. The filters can be successfully fabricated on etched thick film alumina substrate with excellent performance.

For purposes of background, a description of a millimeter wave filter for surface mount applications that uses at least one low temperature co-fired ceramic layer and coupled line, millimeter wavelength resonators formed from stripline or microstrip and positioned on an outer filter surface are described relative to FIGS. 1-6, which correspond to the disclosure of FIGS. 4-9 in the incorporated by reference '404 patent. The structures shown in FIGS. 1-6 can be modified for use with the present invention. Hairpin resonators folded upon themselves can be formed on the filter surface.

Referring now to FIGS. 1-3, there is illustrated a hairpin filter structure as a surface mount package, using thick film, low temperature co-fired ceramic materials. FIG. 1 shows an exemplary hairpin filter formed as a two-pole filter **20** with individual hairpin resonators **22**. The filter uses an alumina carrier plate **24** that is about 25 mil thick, in one non-limiting example, and acts as a dielectric base plate having opposing surfaces. A ground plane layer **26** is formed on a surface of the dielectric base plate **24**. A low temperature co-fired ceramic layer **28** is positioned over the ground plane layer **26** and defines an outer filter surface **30**. This low temperature co-fired ceramic layer **28** can be formed of a layer of low temperature co-fired ceramic tape **28**, which could also be Low Temperature Transfer Tape (LTTT) formed as green tape. In this illustrated aspect, it is formed about 5 to about 7 mils thick with a ground plane layer separating the dielectric base plate and the green tape layer.

A plurality of coupled line millimeter wavelength hairpin resonators **22** are formed as either

stripline or microstrip and positioned on the outer filter surface **30**. Radio frequency terminal contacts **32** are positioned on the surface of the dielectric base plate opposite the low temperature co-fired ceramic layer **28** formed from the green tape. As illustrated, conductive vias **34** extend through the low temperature co-fired ceramic layer **28**, ground plane layer **26**, and dielectric base plate, i.e., carrier plate **24**, and each interconnect the radio frequency terminal contacts **32** (FIG. 3) and the end positioned coupled line resonators **22a** formed on the outer filter surface **30**.

The dielectric base plate is formed about 10 to about 35 mils thick (and preferably in one aspect about 25 mils thick) and formed from alumina, also known as aluminum oxide, a well-known ceramic dielectric material. Other dielectric materials could be used as suggested by those skilled in the art.

As shown in FIG. 2, a lower ground plane layer **35** can be positioned on the surface of the dielectric base plate **24** opposite the upper positioned ground plane layer **26** and the green tape layer **28** and isolated from the radio frequency terminal contacts as illustrated by the two parallel formed lines. A plurality of isolation vias **36** extend through the low temperature co-fired ceramic (green tape) layer **28** and dielectric base plate **24** and substantially engage the parallel strips forming the lower ground plane layer **35**. As shown in FIG. 1, the isolation vias **36** isolate the hairpin filter formed by hairpin resonators. A dielectric cover **38** can be positioned over the outer filter surface **30**. This cover **38** has a metallized interior surface **40**, such as formed from gold layer or similar material, that is spaced from the hairpin resonators **22** for generating a predetermined cut-off

frequency. This cover **38** also shields the formed filter from outside interference. The distance between the microstrip and the top of the cover is about 20 mils, but can vary depending on what is required by one skilled in the art. If a filter is made of stripline only, a cover **38** will not usually be required.

In FIGS. 4-6, a plurality of green tape layers **50** are formed as low temperature co-fired ceramic layers and positioned over a first ground plane layer. Intervening ground plane layers **52** are positioned between green tape layers **50**. This plurality of low temperature co-fired ceramic layers **50** that are formed as green tape and the interposed ground plane layers **52** form a multilayer low temperature co-fired ceramic substrate board. A plurality of millimeter wavelength, stripline hairpin resonators **54** are formed on the ceramic layers **50** between the outer filter **30** surface and the dielectric base (carrier) plate **24** and isolated by the interposed ground plane layers **52**. As illustrated, conductive vias **57** interconnect the hairpin resonators **56** formed on the ceramic layers and outer filter surface. This configuration illustrates a multilayer, six-pole filter **58**, which is created by cascading three two-pole filters in three different layers, with one microstrip filter **62** and two stripline filters **64**, as illustrated.

These filters described relative to FIGS. 1-6 can have a nominal size of about 150 mil by about 100 mil and can be fabricated on large, six inch single layer or multilayer wafers and cut to size with an appropriate laser. The alumina cover **38** having the metallized interior surface can be attached to the filter using conductive silver epoxy. Where the top

filter resonators are made of stripline only, a cover will not be required.

FIGS. 7 and 8 illustrate a filter of the present invention, showing a hairpin filter **100** and formed from hairpin resonators **102**. The hairpin resonators normally have U-shaped arms as in FIGS. 1-6, but in the present invention, the arms are folded back upon themselves into substantially parallel resonator lines **102a** (shown as six substantially parallel resonator lines in this illustrated embodiment). The hairpin resonators **102** can be formed on the top filter surface **104** of at least one dielectric layer(s) **106** in a similar manner as disclosed with reference to FIGS. 1-6.

In the present invention, the arms of each of the hairpin resonators **102** are folded back upon themselves to reduce the overall size significantly as shown in FIG. 7. As should be understood, the length of the hairpin resonators **102** in a hairpin filter is about a quarter wavelength long at the design frequency and the fractional bandwidth of the narrow band filter is less than 1.5%. It takes more time to synthesize than regular filters.

The hairpin filter as shown in FIG. 7 has folded hairpin resonators **102** and the filter measures less than 320 mil by 320 mil. The hairpin filter can be viewed as a parallel, coupled-line filter having cascaded hairpin resonators **102** that are folded back on themselves. In one aspect of the present invention, each hairpin resonator **102** evolved from sections of half-wavelength open microstrips. Further size reduction is possible by further folding a U-shaped microstrip to form pairs of closely coupled lines. The

area of a resonator is no more than one-third of a U-shaped resonator.

FIGS. 8A and 8B show a surface mount package configuration where the filter **100** is fabricated on standard 5 to about 25 mil thick aluminum substrate with one layer of thick film gold or silver and one ground silver layer for the ground layer **108** (FIG. 8B) as modified from the structure described relative to FIGS. 1-6. The hairpin resonators are formed on the top surface (FIG. 8A). An input and output **110, 111** can be connected to bottom solder pads **114** using vias **116**, as modified from the structure disclosed relative to FIGS. 1-6 and modified for purposes of the present invention.

The hairpin filter **100**, as described with reference to FIGS. 7, 8A and 8B, could have a nominal size of about 320 to about 320 mil and could be fabricated on six-inch ceramic wafers. In present terms, the cost of process material is about $30 a wafer and for a filter this size, the cost per unit would be less than $0.10, which is about 100% cheaper than conventional dielectric resonator filters.

Many modifications and other embodiments of the invention will come to the mind of one skilled in the art having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Therefore, it is to be understood that the invention is not to be limited to the specific embodiments disclosed, and that the modifications and embodiments are intended to be included within the scope of the dependent claims.